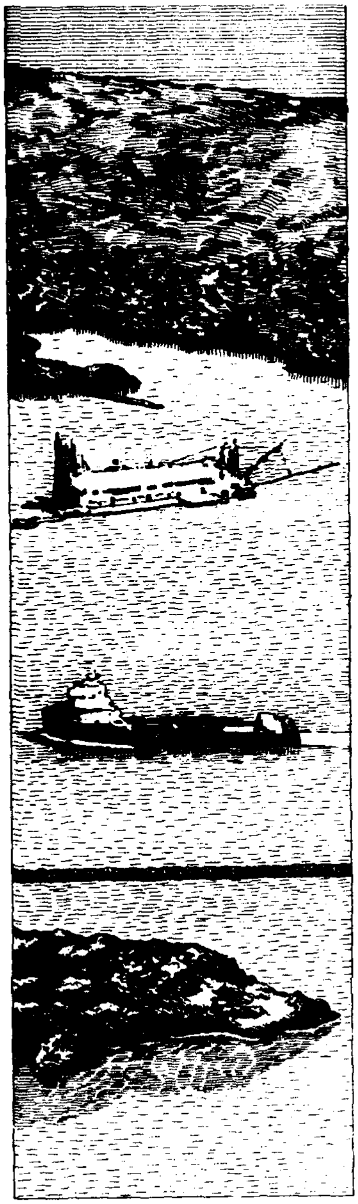
US Army Corps of Engineers



DREDGING RESEARCH PROGRAM

CONTRACT REPORT DRP-93-1

EUROPEAN DREDGING INDUSTRY OVERVIEW WITH EMPHASIS ON GEOTECHNICAL DESCRIPTORS

by

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August 1993

Final Report

Approved For Public Release; Distribution Is Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under Work Unit 32471

Monitored by Geotechnical Laboratory
US Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

The Dredging Research Program (DRP) is a seven-year program of the U.S. Army Corps of Engineers. DRP research is managed in these five technical areas:

Area 1 Analysis of Dredged Material Placed in Open Water
Area 2 - Material Properties Related to Navigation and Dredging
Area 3 - Dredge Plant Equipment and Systems Processes
Area 4 - Vessel Positioning, Survey Controls, and Dredge Monitoring Systems
Area 5 - Management of Dredging Projects

US Army Corps of Engineers
Waterways Experiment Station

Dredging Research Program Report Summary

European Dredging Industry Overview With Emphasis on Geotechnical Descriptors (CR DRP-93-1)

ISSUE: Development of standard dredging-related descriptors of sediment to be dredged is a critical need for the Corps national dredging program. A commonality should be established to promote the flow of information from the geotechnical engineers to planning and estimating functions to the contractors and finally to the dredgers. There are satisfactory methods to measure in situ geotechnical parameters, but there are no standards of interpretation of test results or for correlation between the material to be dredged and dredging equipment performance.

RESEARCH: The Issue is being addressed in a number of DRP studies. This phase included a survey of international literature pertaining to the European dredging industry and discussions with various dredging experts in Holland, England, and Belgium. Emphasis was placed on the use of geotechnical descriptors by the dredging industry and researchers. The information that was gathered in the survey and the discussions will be one source used in the development of geotechnical descriptors and guidance for determining the dredgeability of bottom sediments.

SUMMARY: The European dredging industry and government agencies have supported both basic and applied research for many years. Because of the industry/government relationship, much of the research is proprietary, and it was difficult to discern a systematic approach to determining the relative ease (or difficulty) of dredging operations. However, there is information available from their research efforts that is now in the public domain.

AVAILABILITY OF REPORT: The report is available through the Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, telephone number 601 634-2355.

To purchase a copy of the report, call NTIS at 703 487-4780.

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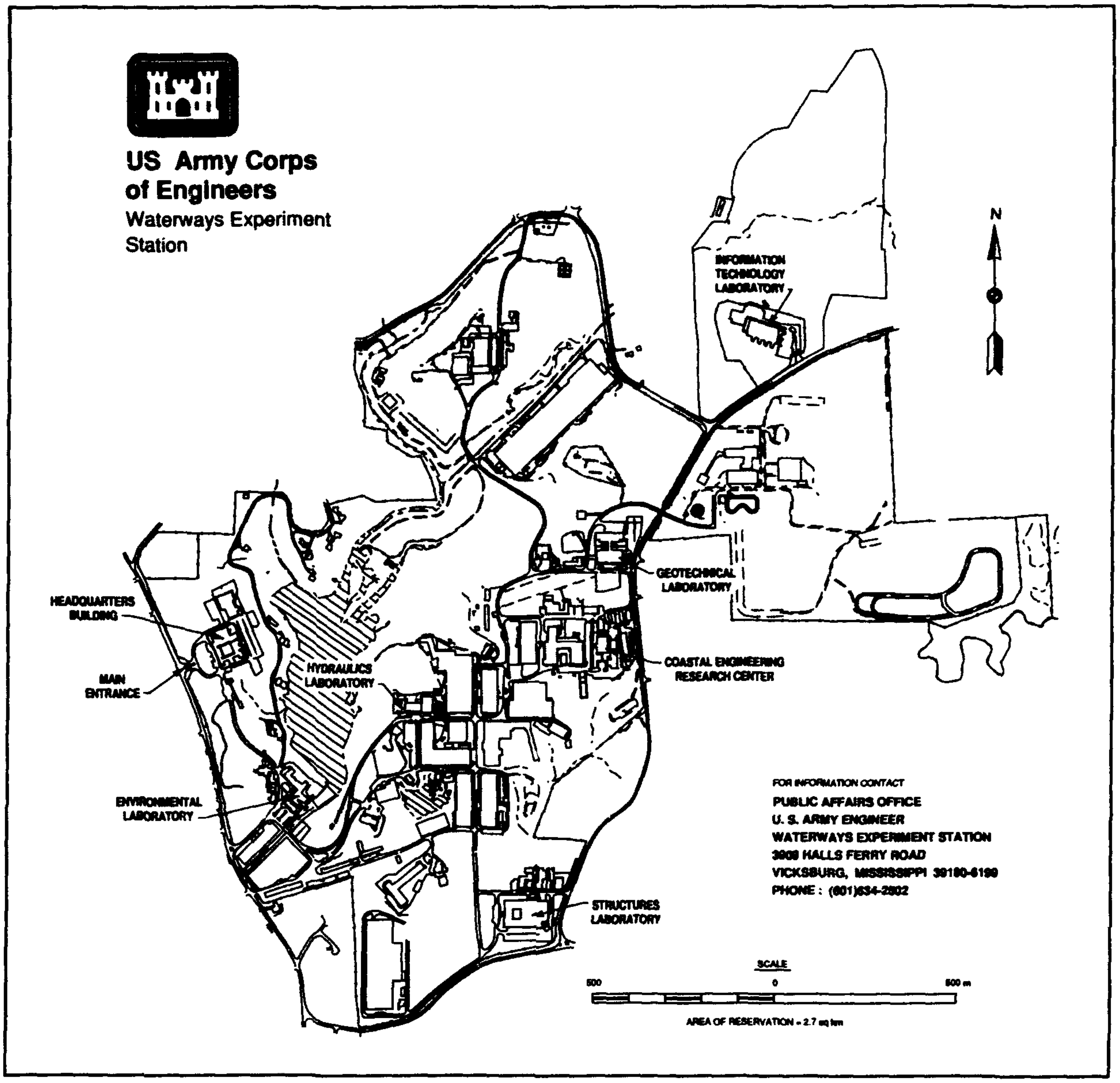

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Preface

This report was prepared under an Intergovernmental Personal Agreement (IPA) No. 88-63-C for the US Army Engineer Waterways Experiment Station (WES). The work was performed under the Dredging Research Program (DRP) Work Unit 32471, "Descriptors for Bottom Sediments to be Dredged." The DRP is sponsored by Headquarters, US Army Corps of Engineers (HQUSACE). HQUSACE Chief Technical Monitor was Mr. Robert H. Campbell; Mr. Barry W. Holliday was Technical Monitor for DRP Technical Area 2.

This report was written by Dr. Wayne A. Dunlap, Professor of Civil Engineering, Texas A&M University, College Station, Texas, under the supervision of Dr. Jack Fowler, Principal Investigator, Soil Mechanics Branch (SMB), Soil and Rock Mechanics Division (S&RMD), Geotechnical Laboratory (GL), and Mr. Milton Myers, Chief, SMB, GL; Dr. Don C. Banks, Chief, S&RMD, GL; and Dr. W. F. Marcuson III, Chief, GL. Dr. Banks was also the Manager for Technical Area 2, Material Properties Related to Navigation and Dredging, of the DRP. Mr. E. Clark McNair, Jr., and Dr. Lyndell Z. Hales, Coastal Engineering Research Center (CERC), WES, were Manager and Assistant Manager, respectively, of the DRP. Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., were Chief and Assistant Chief, respectively, of CERC, which oversees the DRP.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

For further information on this report or on the Dredging Research Program, please contact Mr. E. Clark McNair, Jr., Program Manager, at (601) 634-2070.

Contents

Summary

This report briefly discusses the state of the art of dredging in The Netherlands, Belgium, and England and the result of a survey of the present use of geotechnical descriptors in the European dredging industry. Geotechnical descriptors are ways of describing or defining geotechnical properties of soils or sediments which affect their ability to be dredged. Descriptors may be used to describe new-work and maintenance dredging material. Descriptors may include physical and mass properties such as toughness, friability, fissility, strength, and density (unit weight), or they may take on the form of soil classifications.

Several of the world's leading dredging companies are located in The Netherlands, and probably more research and thought have been put into dredging here than any other country. The main centers of expertise for dredging in The Netherlands are the Delft Technical University, the Delft Geotechnical Lab, the Delft Hydraulics Lab, the Public Works Department, Harbor Division of the Municipality of Rotterdam, and The Rijkswaterstaat. The Netherlands is also the headquarters for CEDA (Central Dredging Association) and IADC (International Association of Dredging Companies). Since much of the research and consultancy is supported by industry rather than by the government, much of the information regarding their work is considered to be proprietary, but a considerable amount of work is being published in international technical journals. Much of this reported work is considered to be outdated, and the sponsoring industries feel they have the competitive edge and no longer feel threatened by release of this information.

The European dredging industry appears to be more technically and highly developed in some areas than the United States dredging industry because the industry and government agencies, especially in The Netherlands, have supported both applied and basic research for many years. This industry/government relationship has resulted in the development of superior laboratory facilities devoted to dredging studies, development and discovery of the various parameters important in the dredging process, and concurrent development of numerical models and computer programs. Because of this relationship much of the dredging research is proprietary, and it is difficult to determine whether there is a systematic approach to determining the ease or difficulty of dredging. There does not appear to be a standard set of

geotechnical descriptors in use by the European dredging industry or government, but it is felt that there is enough information available from their research efforts now in the public domain to aid the US Army Corps of Engineers in the development of geotechnical descriptors for bottom sediments.

EUROPEAN DREDGING INDUSTRY OVERVIEW WITH EMPHASIS ON GEOTECHNICAL DESCRIPTORS

Introduction

1. In connection with an Intergovernmental Personal Agreement with the US Army Engineer Waterways Experiment Station, information concerning the present use of geotechnical descriptors in the European dredging industry was obtained from England and The Netherlands. Broadly speaking, geotechnical descriptors are ways of defining the geotechnical properties of soils or sediments which are to be dredged. Descriptors may include the following properties, as well as means of measuring these properties: toughness, friability, fissility, strength, and density (unit weight), or they may take the form of soil classifications. Descriptors may be used to describe both new and maintenance dredging materials; hopefully, they will be valid for both types of dredging activities.

2. Information was obtained primarily from The Netherlands, although both Belgium and England have recognized areas of expertise in dredging. However, dredging has been a necessity of life for several centuries in The Netherlands. Several of the world's leading dredging companies are located in The Netherlands, and probably more thought and research has been put into dredging in The Netherlands than in any other country.

3. The main centers of expertise for dredging in The Netherlands are the Delft Technical University, the Delft Geotechnical Laboratory, the Delft Hydraulics Laboratory, the Public Works Department, Harbor Division of the Municipality of Rotterdam, and The Rijkswaterstaat. The last is a public institution, somewhat analogous to the civil works area of the US Army Corps of Engineers. The Netherlands also is the headquarters of CEDA (Central Dredging Association) and IADC (International Association of Dredging Companies). The latter are not technical organizations, but they do disseminate considerable technical information through professional magazines and technical meetings.

4. Similar technical organizations for dredging do not exist in England or Belgium. Rather, work is carried out through different organizations on a case-by-case basis using personnel who are not solely dedicated to dredging.

There are numerous consultants in both countries who are very much involved in dredging work, and who have made contributions to the dredging industry by virtue of their work.

5. This report briefly discusses the state of the art of dredging in The Netherlands, Belgium and England from the standpoint of geotechnical descriptors and geotechnical practice in general in the dredging industry.

Delft Geotechnical and Delft Hydraulics Labs

6. Delft Geotechnical and Delft Hydraulics Laboratories, both located in Delft, The Netherlands, are semi-governmental, not-for-profit laboratories which were formed prior to World War II. Although they have been underwritten by the Dutch government for many years, it is understood that this support ceased in 1989, and the laboratories became self-supporting. They perform research and consultancy in their respective fields, and since they are primarily supported by industry rather than government, much of the information regarding their work is considered proprietary. Some of their work is published in international technical journals, but mainly this is work which was conducted for the government or which has been released by the sponsors. It is likely that the sponsored work which has been released is outdated, or that the sponsoring industries have gained a competitive edge on the research topic and no longer feel threatened by the release of information on their research.

7. Mainly the work is centered at the Cutting and Dredging Technology group of the Delft Hydraulics Lab, although this group works with and heavily relies on the Delft Geotechnical Lab for more geotechnically oriented aspects of the problems. Most of the research is sponsored by the Dredging Research Association, which is composed of five large Dutch dredging organizations and The Rijkswaterstaat. The group, which has recently been combined with the Industrial Hydrodynamics group, contains about 30 people (Figure 1). The group is primarily concerned with the physical processes involved in the suction and jetting of sand, clay, and soft rock. This work is significantly aided by two major experimental facilities, a cutting rig and a cutter and trailing suction flume.

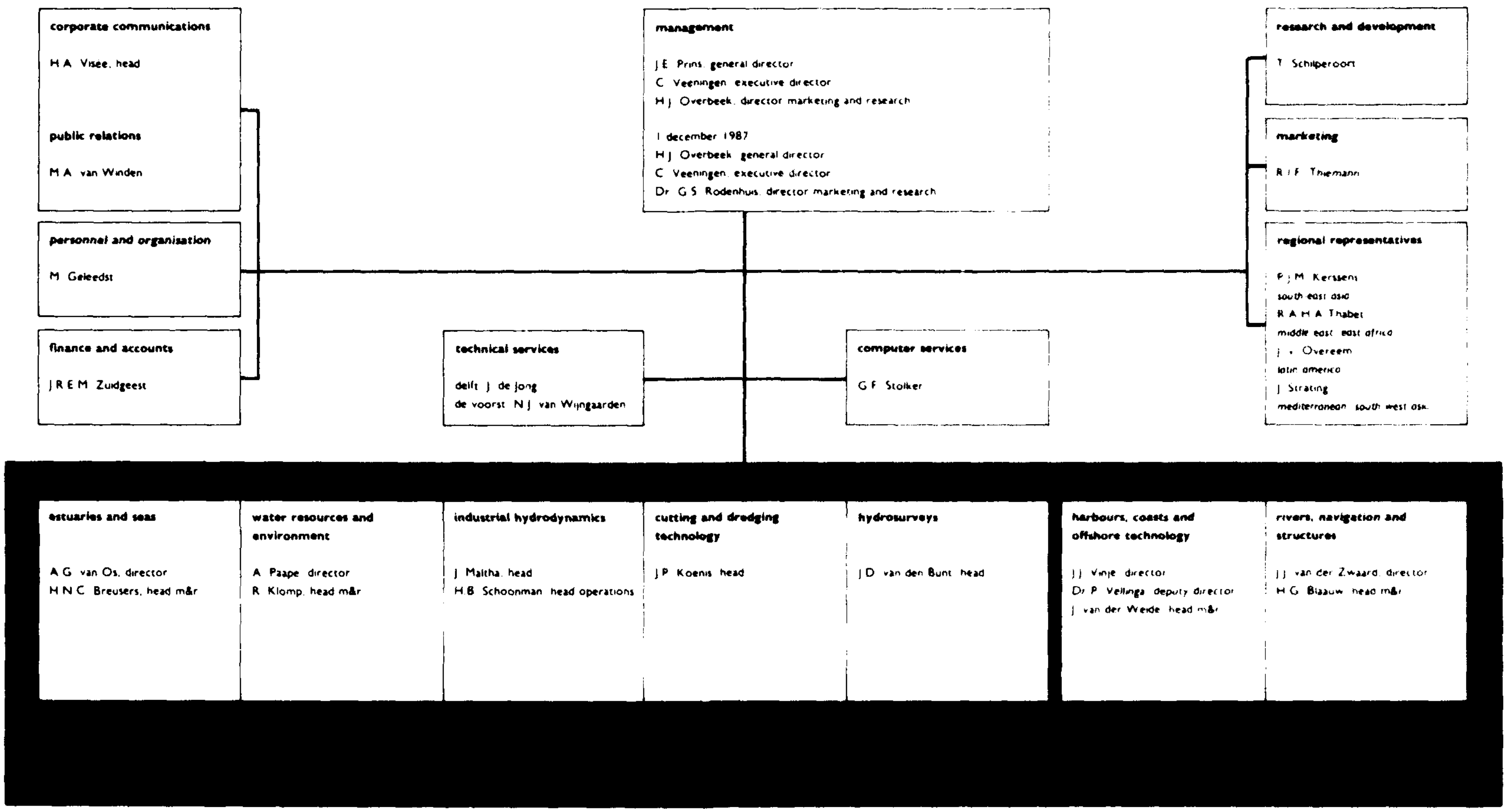

Figure 1. Organization of Delft Hydraulics Laboratory

Cutting rig

8. The cutting rig is used to determine the forces necessary to cut sand, clay, rock, and ice, and it also allows the examination of forces on various cutting tools. The results can be used both for the design of equipment and for such aspects as determining the power required to cut various soils and rock. The rig consists of a sample container which holds a sample of maximum dimensions 0.7 by 0.9 by 6 m long (Figure 2). The sample can be rolled into a pressure tank where pressures up to 4 bars (4 times atmospheric pressure) can be applied, thereby simulating the ambient pressures in the field. (Based on experience obtained at Texas A&M, it is felt that this is a very important aspect of the facility, since the ambient pressure can have a considerable influence on the stress-strain behavior of soils when subjected to stress.)

Figure 2. Cutting rig

9. This is an impressive facility, both for its sheer size and for the facilities associated with it. The latter include equipment for preparing large uniform samples of clay and sand which must be saturated for proper modeling. The instrumentation and data recording equipment also are outstanding.

Cutter and trailing suction flume

10. This is a large flume, 9 m wide by 2.5 m deep by 50 m long, on which a traveling platform is mounted (Figure 3). The platform contains

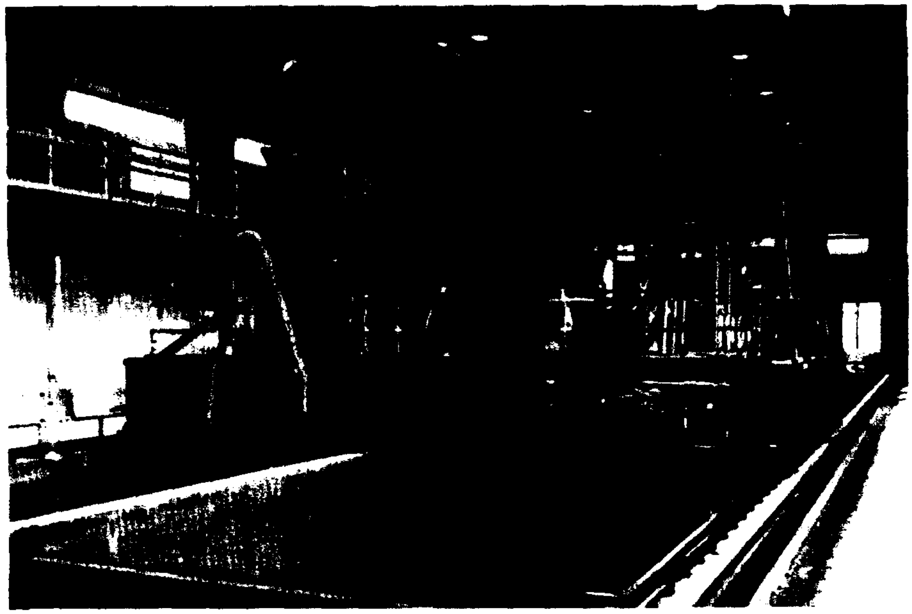

Figure 3. Cutting and trailing suction flume

motors, pumps, and monitoring equipment where a cutterhead or suction arm can be mounted to perform nearly full-scale dredging tests.

11. As an example of how these two facilities might be used, the design of a single cutterhead tooth might be investigated in the cutting rig. The tooth shape could be experimentally optimized by changing its shape, measuring the cutting forces, and examining the shape of the cuttings. The optimum tooth would then be incorporated into a cutterhead design with the aid of a computer program. Finally, the completed cutterhead would be tested in the cutting flume to determine its actual efficiency by measuring cutting forces and pumping efficiency of the cuttings.

Computing facilities

12. Both the geotechnical and dredging labs seem to have a large number of computer programs that have been especially developed for dredging purposes (Figure 4). In fact, these labs seem to be well ahead of the United States dredging industry in this respect. Certainly, this is due in part to the dedication and dredging experience of the personnel in the two labs. However, the basic knowledge, which comes from experiments in the unique lab facilities, and the support of the dredging industry, which allows basic as well as applied research, contribute much to the success of the numerical modeling.

13. A computer program of significant interest is DREDge in MOtion (DREDMO). DREDMO is a numerical simulation program designed to predict the

coastal engineering and morphology

baak	coastal engineering formula basis
bpp	design of rubblemound bed protection with offshore boundary conditions
breakwat	design of armour layers of statically stable breakwaters and revetments
como	one-line model for coastal development
comor/rivcom	compound two-dimensional model for morphology in coastal zones and river areas
durosta	dune erosion due to storm surge
profile	profile development of dynamically stable rock slopes and gravel beaches

harbour and ocean engineering

bas	time domain simulation of ship motions and mooring forces resulting from wind, wave and current action inside harbours
chop	channel depth optimization program
dredmo	motions of cutter/suction dredge due to wind, waves, current, anchoring and bottom-reaction at the cutter
drocon	wave forces and hydrodynamic coefficients of three-dimensional structures
keil	vertical ship motions in shallow water
pharos	oscillations in harbours or variable water depth
shipma	ship manoeuvering simulation model

sediment transport

sutrench	two- and three-dimensional models for suspended sediment
sustra	transport due to currents and waves
transp	local sediment transport models
unibest/crostran	longshore and cross-shore sediment transport due to waves and currents
wamor	two-dimensional horizontal sediment transport and morphology

wave generation, propagation and kinematics

beach	boundary integral method for the computation of non-linear wave deformation up to breaking
credix	wave propagation and deformation in a horizontal plane due to depth and/or current variations based on the parabolic approximation of the refraction-diffraction equation
endec	wave energy decay along a wave ray path incorporating non-linear dissipative processes due to breaking and bottom friction
gono	wind-wave hindcast model for deep water and shallow seas based on a coupled hybrid wave prediction formulation
hiswa	nearshore wind-wave hindcast model for shallow seas and estuaries based on a directional refraction approach and a parametrization in frequency domain
lingo	computation of refraction and diffraction of linear monochromatic waves
rfwave	local water surface elevations and kinematics according to a stream function method
strobo	refraction of linear water waves in the horizontal plane due to depth and/or current variations based on the ray theory of the geometric optics approximation
veld	post-processing program on STROBO and ENDEC to incorporate the non-linear dissipative processes of the wave field due to breaking and bottom friction
wam	research wind-wave hindcast "third generation" model for deep and shallow water with special emphasis on non-linear wave-wave interaction

dispersion

mitemp	transient thermal behaviour of deep reservoir used as a cooling pond (originally developed by MIT)
pds	three-dimensional transport and dilution of buoyant surface discharge (originally developed by Shirazi & Davis)
salin	salt intrusion in a network of open channels (uses output of NETFLOW)
smoss	two-dimensional oil spill spreading and weathering simulation model (originally developed by the Delft University of Technology)
straal 3D	three-dimensional jet in moving fluid
verdict	vertical diffusion in flows with an arbitrary vertical density distribution

delft hydraulics

Figure 4. Computer programs - Delft Hydraulics Lab

flow

delflo	two-dimensional averaged flow with or without turbulence modelling, structures, external forces etc.
distro	non-homogeneous tidal flow in vertical plane (temperature included)
frimo	model for two-dimensional steady flow
netflow	unsteady flow in river networks
odyssee	two-dimensional, non-hydrostatic fluid flow with or without turbulence modelling in complex geometries (developed in cooperation with the Laboratoire National d'Hydraulique, France)
sym 3D	three-dimensional hydrostatic fluid flow in complex geometries (originally developed by the Rand Corporation, USA)
trisula	three-dimensional water movement and transport
twolay	two-layered systems in prismatic channels (hot/cold or salt/fresh water)
waflow	unsteady flow in river networks
waqua	two-dimensional depth-averaged unsteady flow and transport of dissolved matter (originally developed by the Rand Corporation in USA)
wilma	waterhammer phenomena with or without cavitation in networks of closed conduits with control devices

hydrology

cadis	computer aided design irrigation systems
grodra	saturated groundwater flow including drainage to surface water
gromula	groundwater flow in one or more mutually connected horizontal layers
hymos	hydrologic data processing for water management systems
predis	investigation of effects of human interference in various components of the hydrological cycle
somof	non-steady soil moisture flow in the unsaturated zone

system analysis and water resources systems

aad	coupled version of ABOPOL, ARIADNE and DEMGEN
abopol	simulation of water and salt flows in a free-flow network system
ariadne	simulation of water and salt flows in a controlled network system
bansim	agricultural production model for evaluation of flood protection and irrigation strategies
cowadat	data-base management system to evaluate coastal water management strategies
demgen	prediction of regional water flows and salt flows and resulting agricultural crop damage
dripro	forecast of water supply demands for households, industry and agriculture
drisim	dynamic evaluation of alternative drinking-water supply systems
optinet	minimization of investment and energy costs for design of hydraulic networks
resdm	optimal allocation of groundwater between industry and water companies
ribasim	hydro-economic evaluation of river basin development schemes
siris	simulation of irrigation systems

time series analysis models

getijsys	harmonic analysis of tides
golana	on-line time series analysis (waves, etc.)

water quality

beek	phosphorus and nitrogen processes in tributaries
bloom II	algae bloom in lakes or shallow reservoirs
cabamod	carbon budget model of salt water ecosystems
charon	chemical model to calculate the chemical composition in surface water and groundwater
crewaq	multi-dimensional marine ecosystems model
delqua	two-dimensional depth-averaged dispersion of multi-component pollutants
delwaq	multi-dimensional water quality model (can use output of WAQUA)
dynaqual	quasi-dynamic water quality model for rivers and riverine systems
impaqt	fate of organic micropollutants in surface water and sediments
metcos	heavy metals concentration in a lake with pH-dependent adsorption and sedimentation
metsal	dispersion of heavy metals in an estuary with a salinity gradient and tidal motion

Figure 4. (Continued)

midas	dynamic phyto-plankton model for lakes and reservoirs
modqual	steady state mathematical model for water quality calculation in river systems
nitsol	nitrogen transport through the unsaturated part of the soil
optmos	optimization of sampling frequency, station location and selection of parameters for water quality monitoring networks
phosol	phosphorus transport through the unsaturated part of the soil
resqua	water quality model for stratified reservoirs
seawaq	dynamic phytoplankton model for marine systems
storm	model quantifying waste loads from storm water treatment, overflow and run-off in areas with combined sewer systems
swip 2	one, two, and three-dimensional groundwater flow with quality and density differences
uptage	bioaccumulation of micropollutants in aquatic food chain

navigation

meer	forces in hawsers of moored ships
shipma	ship manoeuvring simulation model
sports	simulation of port operation
watrans	simulation of inland waterways transport

protections

clodes	design of closure works

rivers and canals

rivcom/comor	compound two-dimensional model for morphology in coastal zones and river areas
rivmor	bed load transport and bed configuration in river systems
seflow	sediment transport and bed configuration in open channel networks
seres	sedimentation in reservoirs
sused	suspended sediment transport in non-tidal flow

structures

bots	forces on mooring structures due to berthing procedures
tros	hawser forces of ships in locks
pumps	three-dimensional potential flow in pump impellers

Figure 4. (Concluded)

behavior of seagoing dredges in swells. DREDMO harbors a great deal of varied research in the guise of input to the program. For example, the research at Delft Technical University on cutting forces on cutterhead and bucket wheel dredges in sands was conducted for input to DREDMO.

Delft Technical University

14. A relatively large dredging research group has been formed at Delft Technical University. The group is administratively located in the Mechanical Engineering Department, and their prime interests are equipment development and efficiency of pumps. However, there has been significant technology spillover in pursuit of these efforts, and the group now has expertise in several areas. A member of the group recently completed a PhD dissertation on cutting forces on sands which could easily be classed as a dissertation in geotechnical engineering. His work paralleled that being conducted at Delft Geotechnical Lab.

15. The university group has a cutter suction flume, similar in many respects to the larger flume at Delft Hydraulics Lab. Although the university flume is smaller, it has many similar features including a length of transparent side which allows direct observation of the dredging action during tests. It, too, is well instrumented to obtain cutting forces, and is controlled with respect to speed of movement and other factors.

Port of Rotterdam and Rijkswaterstaat

16. The Port of Rotterdam (in cooperation with The Rijkswaterstaat) is conducting some applied research on dredging. Much of this is in conjunction with dredging and disposal of maintenance material under the M.K.O. project (Minimization of Dredging Costs), and with the determination of the navigable depth in the Rotterdam Harbor. The Port has a well-equipped geotechnical lab which conducts various special tests for dredging purposes, but there are no special laboratory facilities for dredging alone. One of more progressive aspects is the use made of navigational and positioning computers in the harbor dredging. Bathymetric surveys for dredging purposes are computerized, and the areas requiring dredging are delineated. Dredgers are supplied with computers and navigational equipment which show in real time the areas to be

dredged and the depth of dredging. Other applications, such as the use of silt curtains in the harbors, are ingenious but are beyond the scope of this report.

Geotechnical Descriptors

17. Discussion by the writer with the various dredging experts in The Netherlands, England, and Belgium did not reveal a standard set of geotechnical descriptors for dredging purposes. Perhaps the closest thing to geotechnical descriptors is the recently revised (1984) PIANC classification for soils to be dredged. However, there is almost universal feeling among those consulted that the PIANC descriptors are generally inadequate. It is interesting to note that in a recent paper by Verhoeven, Jong, and Lubking (1988) the Unified Soil Classification System was recommended for classifying soils although it was stated that the paper could be regarded as extra background for the PIANC soil classification. "Dredging parameters" is a term often used in The Netherlands for determining what geotechnical factors should be considered in planning a dredging (not disposal) operation. Consolidation characteristics, shear strength, and viscosity (for weak sediments) are considered the most important parameters; however, there seemed to be no universal formula to determine dredgeability which included these parameters. Quite possibly, these parameters are utilized by individual companies in some fashion to obtain a geotechnical dredging descriptor, but it is the writer's opinion that this is not the case.

Shear Strength

18. By far the most prevalent means of determining shear strength of competent soils and sediments to be dredged is the Cone Penetrometer Test (CPT). This is not surprising, considering that the test was originated in The Netherlands and that it has received considerable publicity in attempts to export the technology. A considerable amount of research and correlation efforts are still going on in The Netherlands with the CPT, both within and outside the dredging industry. For instance, although the electric cone is almost universally used today, much early work is done with the original (Begemann) Dutch cone. The Delft Geotechnical Lab has an ongoing project of

revisiting Dutch cone sites with the electric cone to develop and check correlations between the two tests. Research also is being conducted with the CPT as a means of determining strength of soft rock (chalks, limestones, and sandstones). It is not clear whether this is primarily for the dredging industry, but it will certainly be helpful in determining whether such materials can be dredged by cutterhead dredges equipped with rock picks.

19. Because of the popularity of the CPT, there are a large number of CPT trucks available in both the private and governmental sectors in The Netherlands, Belgium, and England. Consequently, the CPT has become, in addition to being a strength-measuring device, a delivery system for other in situ measuring instruments which may have usefulness in the dredging industry. These other measurements include permeability (Figure 5), density (unit weight), water content, salt content, pH, and groundwater sampling.

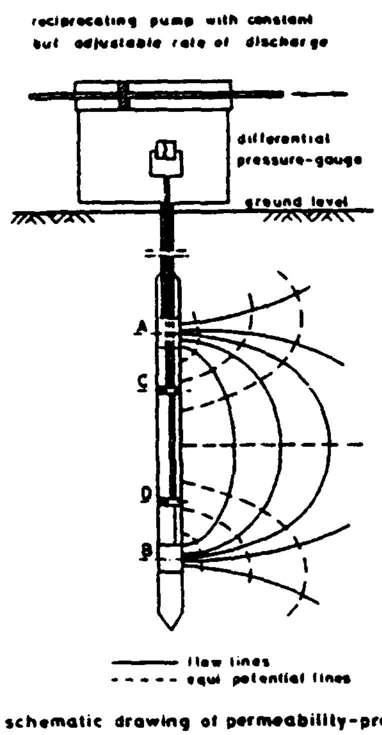

Figure 5. Permeability probe developed
at Delft Geotechnical Lab

20. The dredgeability of sands has been studied extensively at the Delft Geotechnical Lab and at the Delft Technical University. The angle of shearing resistance, the state of denseness and the permeability of the sands, and the friction angle between the cutter blade and sand have been found to be important parameters affecting the cutting forces. The state of denseness is

important because of its effect on shear strength and volume change during shear. If the sand is dense, it will attempt to dilate during the cutting process. The shearing velocity and length of drainage path are generally large enough that the water in the shear zone cavitates during dilatancy, which produces additional shearing resistance in the sand due to the negative pore-water pressure. This concept has been proven at the Delft Hydraulics Lab by the installation of miniature pore-water pressure transducers on cutting blades during tests in the cutting rig.

21. Delft Technical University examined the effects of cutterhead swing velocity with respect to cutterhead rotation speed for both undercutting and overcutting to set up a mathematical model for cutterhead forces. The model was then verified with tests on sand in the cutting rig. These tests showed that the "cutting forces and the driving torque increased almost linearly with the cone resistance of the sand." It also was shown that as the ratio between the circumferential velocity and the swing velocity increased, the shape of the cut layers formed during overcutting and undercutting gradually became more similar (Figure 6).

22. The work done on cutting of clays has not received as much publicity as the sand problem, but there has been research on clays conducted in the cutting facility at Delft Hydraulics Lab. One of the main findings of those efforts is the different modes of deformation exhibited by soft and stiff clays. Soft clays show a plastic type of deformation as the cutting blade advances (Figure 7), whereas in stiff clays a crack propagates from the tip of the cutting blade (Figure 8). As a consequence the force required to cut stiff clays may be less than that required to cut softer clays, a total reversal of commonly accepted concepts.

23. The results of this work are still classed as proprietary, and there is no information in the public domain to determine what common methods might be available to separate plastic behavior from brittle behavior. Apparently all tests in the cutting rig facility were conducted on remolded clays. The fabric of natural clays (e.g., fissured clays) might significantly influence the mode of behavior of these clays during cutting. It was reported that the dredging companies which supported this research on clays are utilizing this information, but it is not clear how they are using it.

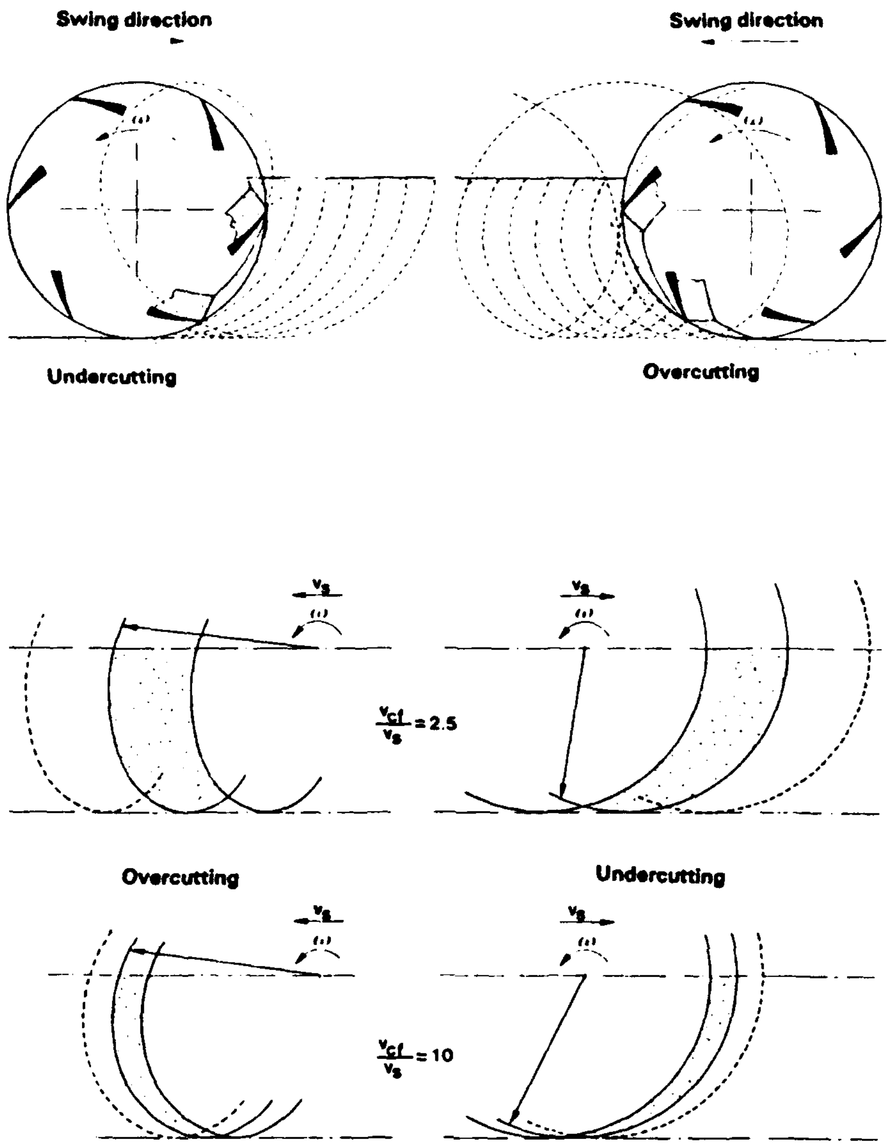

Figure 6. Development of undercutting and overcutting dredge cutter models (after Miedema 1984)

Viscosity

24. An indirect approach to the strength determination of fluid muds for maintenance dredging is to make viscosity measurements using a "rheometer" (De Meyer and Malherbe 1987). Similar measurements can be made with a precise vane shear device. The rheometer (Figure 9) is deployed on a wireline from a vessel and allowed to settle to the depth where measurements are desired.

Figure 7. Plastic deformation in clay produced by cutter tooth

Dynamic viscosity and initial rigidity are determined. According to De Meyer and Malherbe (1987), the measurements from the rheometer are better indicators of the navigable bottom than density alone since certain fluid muds may have sufficient strength to prevent ship maneuvering even though the density of the mud may be below 1.2.

Unit Weight (Density)

25. Nuclear probes suitable for making sediment density measurements underway have been developed by several groups in The Netherlands. The feature which allows measurements to be made without holding the probe still is the high level of counts received by the detector and photomultiplier in the probes, reportedly about 25,000 counts per sec. The density probe used by the Port of Rotterdam is available commercially from T.N.O. Rijkswaterstaat's probe may eventually be made by others. Delft Geotechnical Lab also manufactures a density probe which they claim is superior to others because it is not influenced by changes in materials. Both direct transmission and backscatter probes have been used (Figure 10). Both probes are deployed by a wireline from a vessel. The backscatter probe penetrates deeper into the sediment, but it is less accurate than the two-element direct transmission probe. An inclinometer is mounted on the backscatter probe to determine whether it travels vertically through the sediment. The direct transmission probe can be towed behind a boat through low density (fluid mud) sediment to measure the specific gravity for the purpose of determining navigable depth.

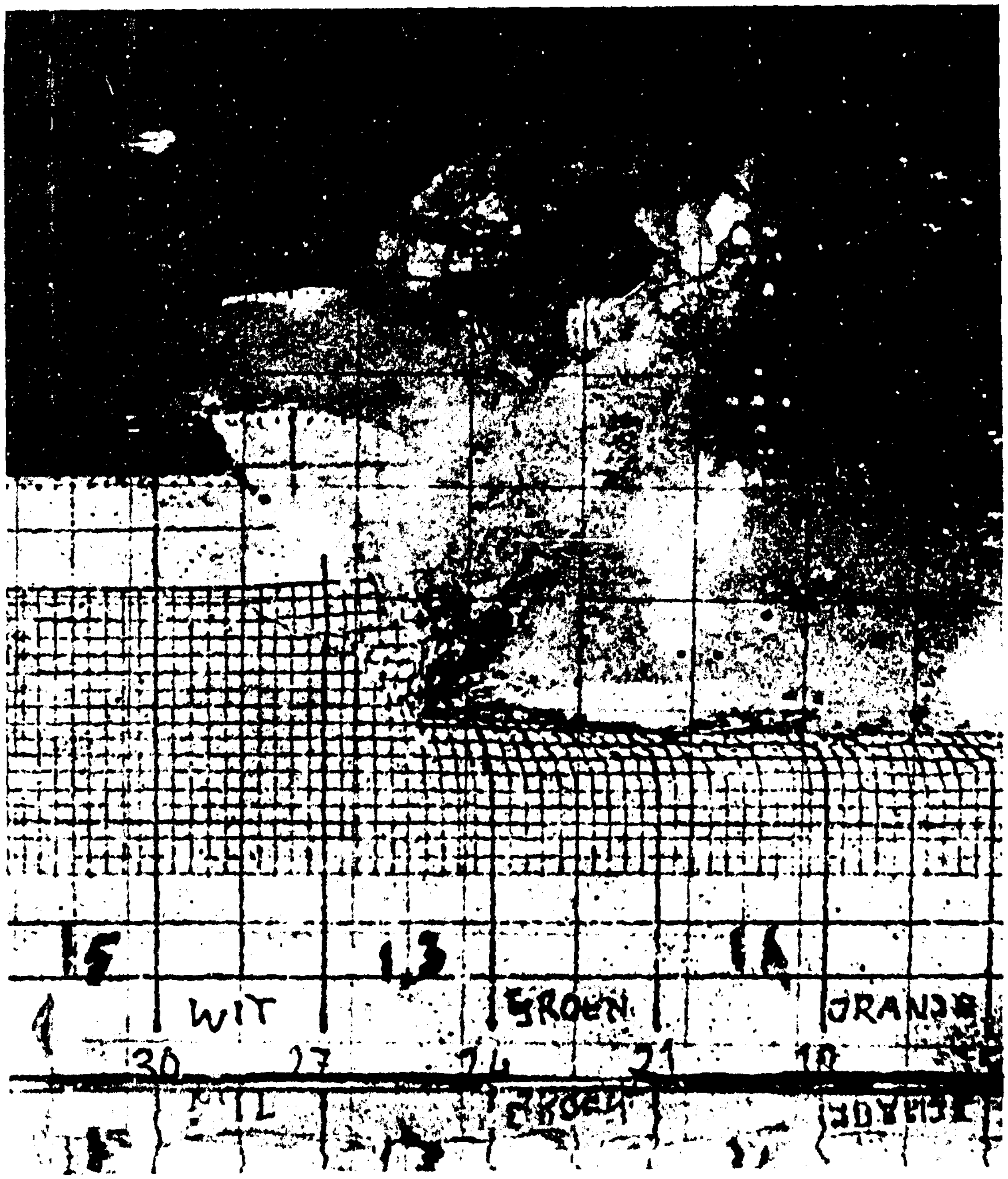

Figure 8. Brittle deformation and crack propagation in stiff clays

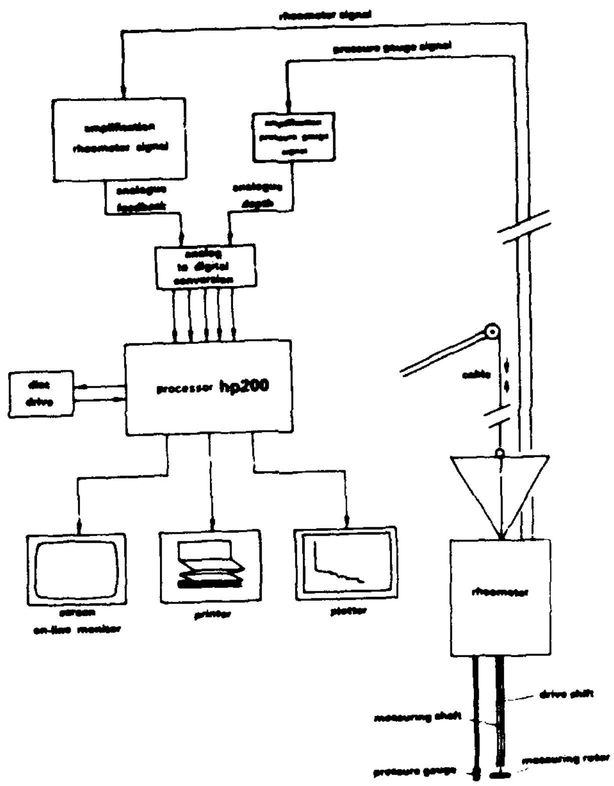

Figure 9. Rheometer developed by De Meyer and Malherbe (1987)

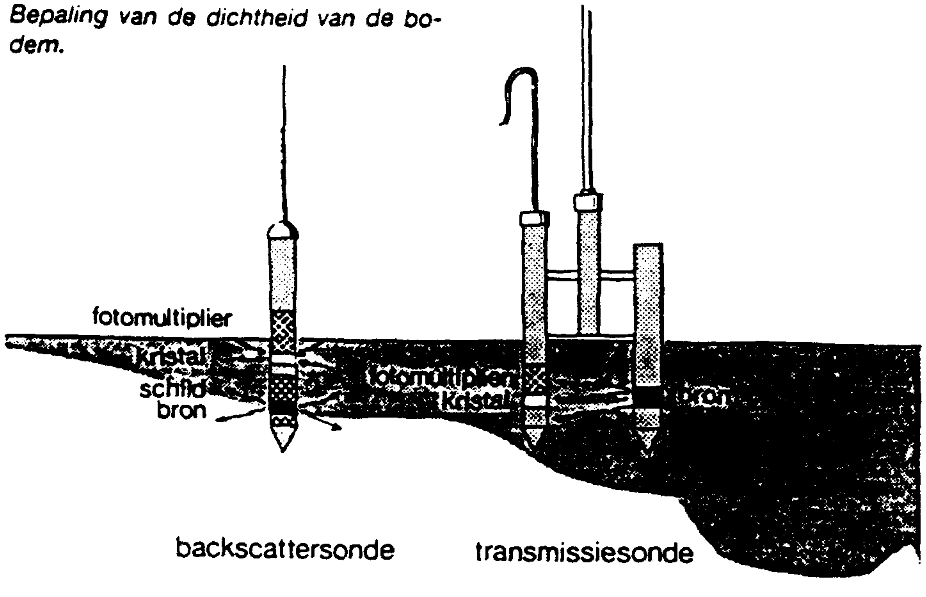

Figure 10. Backscatter and direct transmission nuclear probes

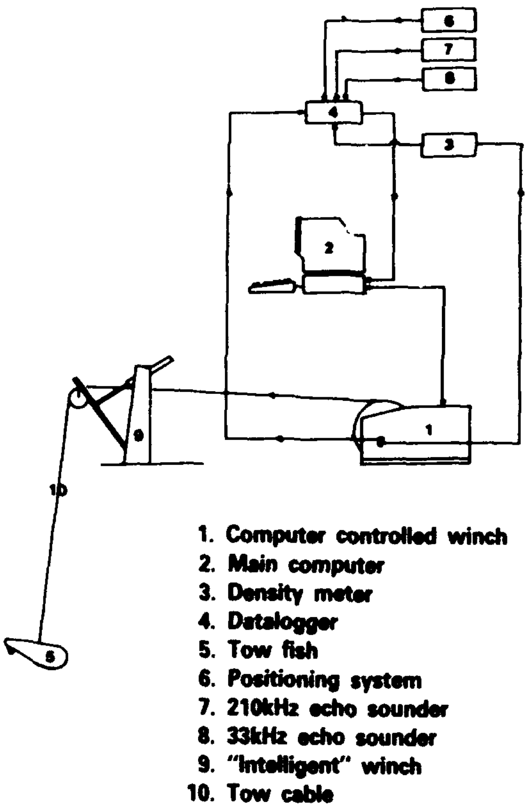

Figure 11. Schematic of the Navitracker system

26. Another device for measuring sediment density, especially in regard to the navigable depth concept, is the Navitracker developed in Belgium and England (De Vlieger and De Cloedt 1987). This apparatus (Figure 11) is a towed nuclear density device which is operated by a "smart" winch mounted on the towing vessel. The winch is controlled by a computer which, in turn, controls the depth that the density device is lowered into the soft sediment. It can be pre-set to find the depth at which the sediment density is, for example, 1.2, thus establishing the navigable depth.

Acoustic Methods

27. Acoustic or seismic methods have played a major role in the European dredging industry for some time, particularly in the maintenance dredging area. Considerable research has taken place to evaluate and interpret signals from these methods, and to develop new equipment. For example, a "nonlinear echogram" is presently being tested at the Port of Rotterdam by Rijkswaterstaat. This is an acoustic subbottom profiler, mounted on a boat (Figure 12), which sends out several frequencies, thereby allowing the detection of different levels of density in the sediment. Apparently there are interpretation problems with the signals, especially when thin layers with large density gradients are encountered, but tests are continuing in two different types of silts in an attempt to work out the problems.

28. Europort and the Port of Rotterdam have a regular system of bottom surveys which they conduct with several survey boats (Port of Rotterdam alone has six survey boats). Depending on the season, surveys are conducted every 1-1/2 to 4 weeks apart. All positioning of the survey boats is automated. Europort uses a mini-ranger which provides 1- to 2-m accuracy, and is tied into a topographic data base system. Maps are quickly produced to show where dredging is required. The dredgers are supplied with the same type of equipment, along with on-board computers which show on the screen in real time the plan view of the docks, the location of the dredge arm, and the location and depth of dredging required. Post-plots are provided after dredging is completed. Therefore, the process of dredging is very automated. It is hoped that in the future the process will be further automated to the point of controlling (a) positioning of the dredge and (b) vertical positioning of the dredge arm.

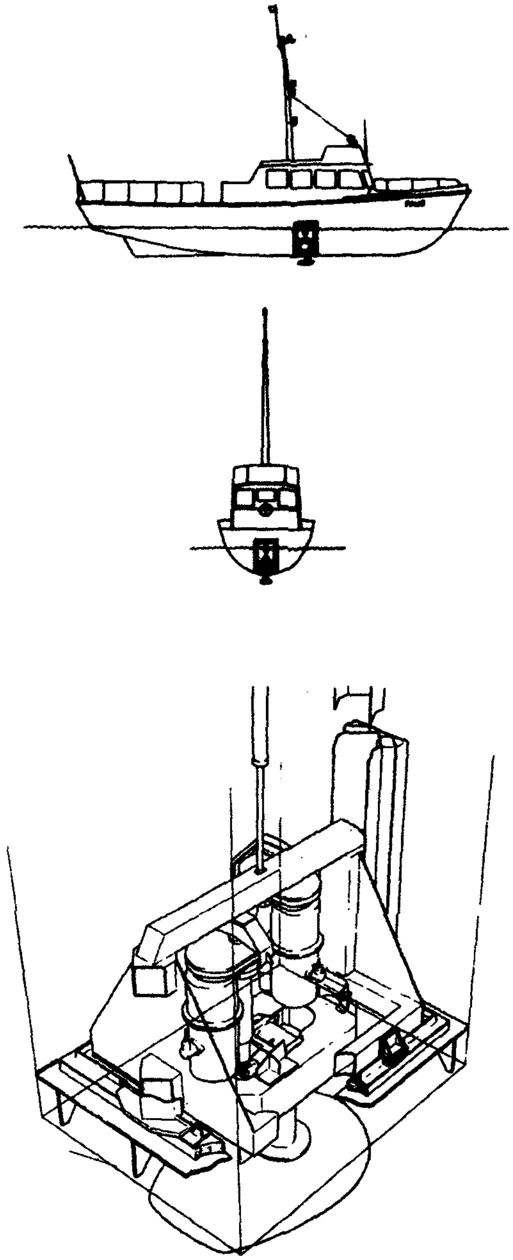

Figure 12. Arrangement of nonlinear echogram equipment

Effects of Gas in the Sediments

29. The sediments in the Port of Rotterdam contain significant organic material which produces biogenic methane. The methane gas influences the consolidation process and the sediment density, and increases the sediment shear strength. These conclusions are based on experience, and so far there

has been no scientific explanation for these observations, particularly with respect to the shear strength increase. Because of the importance of gas on the sediment properties, the Port of Rotterdam developed a gas content meter in connection with the M.K.O. project (Figure 13). This meter can be deployed on a wireline from a ship and allowed to sink to a particular depth where the sediment is sampled for subsequent gas content determination.

Conclusions

30. The European dredging industry, particularly in The Netherlands and Belgium, is technically highly developed in some areas compared to the United States dredging industry. For many years, industry and governmental agencies have supported high-level research, both basic and applied in nature. This has resulted in superior laboratory facilities devoted entirely to the study of the dredging process, development of test methods for determination of various dredging parameters, and the concurrent development of numerical modeling and associated computer programs. It also has produced a group of professionals whose prime interest is dredging research and university curricula in dredging. The dredging companies also maintain well-trained and experienced engineers who are concerned with the dredging process, in addition to equipment deployment. Also, numerous consultants have made significant contributions to the dredging industry in many ways, including major test equipment development.

31. Unfortunately, much of the dredging research being conducted, especially in The Netherlands, is proprietary, and it is difficult to determine whether there is a systematic approach to determining ease of dredging and selection of dredging equipment. There does not appear to be a uniform set of geotechnical descriptors, as envisioned by the Corps of Engineers, in use in the European dredging industry. However, public knowledge available from their efforts can significantly aid in the development of geotechnical descriptors.

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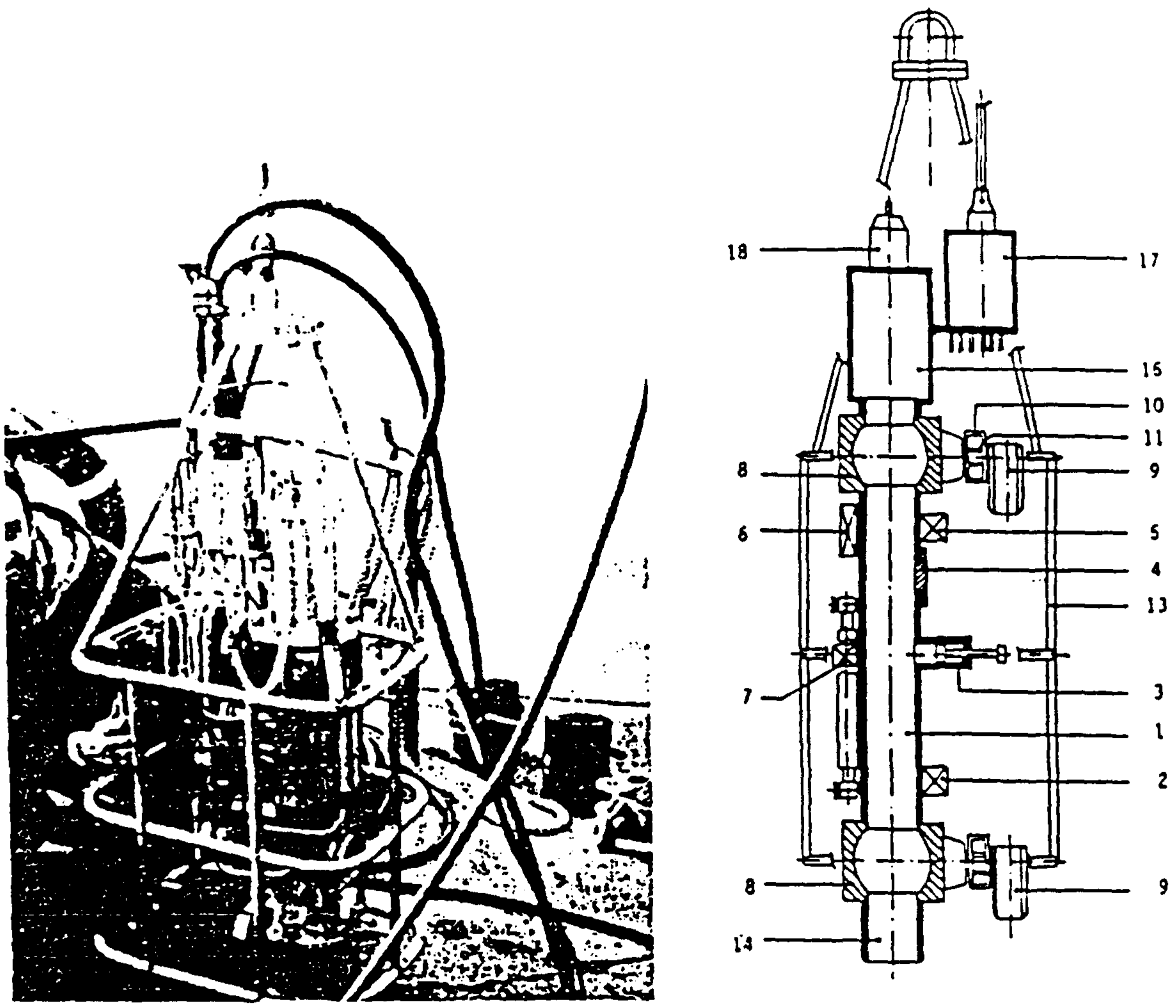

KEY

1. Measuring cylinder
2. Pressure Meter (Differential pressure transducer
3. 10-cc volume regulator
4. Closedflange/Blank flange
5. Depth transducer
6. Thermistor (thermometer)
7. Slope transducer
8. Ball valve

9. Rotary vane motor
10. Clamp/Bracket
11 Joint coupling
13. Cage construction
14. Probe
16. Overflow tank
17. Connection box
18. Level indicator

Figure 13. Gas meter developed by Port of Rotterdam

Vlieger H. de and Cloedt, J. de. 1987 (Dec). "Navitracker: A Giant Step Forward Tactics and Economics of Maintenance Dredging," Terra et Aqua, No. 35.

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13. ABSTRACT *(Maximum 200 words)*

This report briefly describes the state of the art of dredging in The Netherlands, Belgium, and England and the results of literature searches and personal interviews in these countries regarding the present use of geotechnical descriptors in the European dredging industry. Geotechnical descriptors are used to describe or define the geotechnical properties of bottom sediments which affect their ability to be dredged. Dredging research and the dredging industry in Europe are considered to be more technically and highly developed in some areas than the dredging industry in the United States because of governmental support. Because of this industry/government agreement much of the dredging research is proprietary, and it was difficult to determine whether there was a systematic approach to determine the ease or difficulty of dredging. There does not appear to be a standard set of geotechnical descriptors in the European dredging community. It was felt that there was enough public information available to aid the Corps of Engineers in development of standard dredging descriptors for bottom sediments.

14. SUBJECT TERMS

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